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HRMS: WHERE WE'VE BEEN, AND WHERE WE'RE GOING

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ABSTRACT Nearly one year ago, NASA inaugurated the High Resolution Microwave Survey simultaneously at Goldstone, California and Arecibo, Puerto Rico. Since that time, the Targeted Search has completed a 200-hour observing campaign at Arecibo and returned its hardware to Ames Research Center for modification and replication. The Sky Survey has conducted weekly observations at X-band using the new 34 m beam waveguide antenna, and completed a sequence of maps of the galactic plane, primarily at L-band, using the old 26 m antenna at DSS 13 until its decommissioning.

At both sites the equipment has functioned well, with minor, mostly low-tech, glitches. These initial observations have verified the transport logistics for the Targeted Search and provided the first platform for remote observations to the Sky Survey. As a result of the data that have been collected, modifications have been made or planned to the hardware, software, and observing protocols. Both observing programs have encountered signals that required additional observations because they initially conformed to the detection pattern expected for an extraterrestrial signal, but no signals persist as potential candidates at this time.

This paper will discuss the lessons we have learned, the changes we are making, and our schedule for continued observation.

INTRODUCTION

During the Congressional budget cycle for fiscal year 1993, Congress changed the name of NASA's SETI Microwave Observing Project, and NASA changed the project's institutional home from the Life Sciences Division to the Solar System Exploration Division. High Resolution Microwave Survey (HRMS) is now the politically correct name for this exploratory endeavor. The change of programmatic venue enabled a formal new start for a focused research and analysis initiative to discover and characterize planetary systems around other stars; Toward Other Planetary Systems (TOPS). Although the methodology is different from that traditionally used by the TOPS community, HRMS may permit the detection of habitable planets elsewhere by detecting those already inhabited!

HRMS GOALS AND OBJECTIVES: A COMPREHENSIVE SEARCH

HRMS will conduct a systematic search for evidence of extraterrestrial technologies by developing and deploying special purpose signal processing equipment on existing radio telescopes worldwide. HRMS is by no means the only SETI program currently ongoing, or even the only one funded by NASA (others have been discussed elsewhere at this meeting), but it is the most comprehensive search that has ever been undertaken. It makes the fewest assumptions about the exact nature of the signals being transmitted by another technology; it simply requires that they be distinguishable from astrophysical emissions. What constitutes a technological signal? Good candidates are anything that nature appears incapable of producing, but which our own technology routinely produces. This translates into signals that are band-limited in the frequency domain; narrowband signals. Natural emission processes appear to be broadband. Although water masers can achieve a fractional bandwidth of 10^{-6} and there are OH maser features as narrow as 300 Hz, this appears to be the limit for natural, coherent emission mechanisms.

In contrast, we often find it economical to generate signals having very large signal-to-noise ratios that are sub-Hz in width, and have fractional bandwidths as small as 10^{-12}. Such signals would be broadened by multipath scattering in the interstellar medium, but could still arrive at the receiver with widths much narrower than the narrowest OH maser, and be recognizably artificial. Further, these band-limited signals do not have to be continuous, they can pulse on and off at regular intervals, producing attention grabbing signals (like a light-house) for less transmitted power than their continuous (CW) counterpart. To be distinguishable from the natural pulsars, they must be no broader in the frequency dimension than the inverse of their time duration. Their time-bandwidth product must exceed unity, as required by the uncertainty principle, but not by much. Since the signals may not have been intentionally beamed at Earth, HRMS allows for the possibility that some relative acceleration (such as planetary rotation) between sender and receiver will cause the frequency of the narrowband signal to slowly change with time. This degree of freedom, to broaden the class of recognizable signals, significantly increases the difficulty of the signal processing. An upper-limit of $\pm 10^{-9}$ Hz/s/Hz has been invoked to bound the signal drift rate. This corresponds to a Jupiter with an 8 hour day. Lastly, signals do not have to come from any one portion of the sky. The HRMS will use large telescopes around the world, in the North and South, belonging to NASA's Deep Space Network of satellite tracking stations and to research organizations of several nations, in order to conduct this comprehensive search.

Such a comprehensive search is beyond the scope of any individual or small group. The HRMS results that are reported here are the work of a large team of scientists and engineers at Ames Research Center, the Jet Propulsion Laboratory, the non-profit SETI Institute, Silicon Engines Inc., John Reykjalin Inc., Sterling Federal Systems and a group of 9 university scientists selected to form an HRMS Investigators Working Group (IWG) in response to a 1990 NASA Research Announcement.

Since so little (absolutely nothing!) is known about the power density function of signals from extraterrestrial technology, it is impossible to know whether the most detectable signals are intrinsically strong signals coming from a large distance, or relatively weaker signals coming from nearby. If it is reasonable to express the number of transmitters in the range P as $N(P) \propto P^{-\alpha}$ then for values of α less than or equal to 2.5, a sky survey for intrinsically bright sources is more likely to succeed. However, if α is greater than 2.5, the most detectable sources will be weaker ones, from nearby. In the face of this vast ignorance, HRMS will utilize both a sky survey and a targeted search of nearby stars simultaneously. A Sky Survey covering 1 to 10 GHz, (the quiet portion of the microwave window visible from Earth with its atmosphere of oxygen and water vapor) will be made using the new 34 m, beam waveguide antennas of the DSN at both the Goldstone, California and Tidbinbilla, Australia tracking stations.

The Sky Survey tessellates the sky by defining over 25,000 individual "skyframes," each 30 degrees long in right ascension and from 1 to a few degrees width in declination (depending on the observing frequency). Since the antennas must be scanned rapidly over each skyframe to complete the frequency/sky coverage within about 7 years, only a modest sensitivity is achieved. The whole sky will be mapped 30 different times at 30 different frequencies, looking for narrowband ETI signals. These maps can be combined, after the fact, to provide radio astronomy continuum surveys at sensitivities comparable to what has been done in the past, but covering the whole spectral region from 1 to 10 GHz. This is not the reason for HRMS, but it represents some of the secondary science that can come out of looking at the universe with a unique new set of filters.

To complement the Sky Survey, a Targeted Search of about 1,000, nearby, solar-type stars will be conducted with the world's largest telescopes, which generally do not belong to NASA. The larger collecting areas, a long dwell time per source and per frequency (at least 300 seconds, and 1,000 seconds where possible), and a reduced frequency range (1 to 3 GHz, where these telescopes function best), permit the Targeted Search to achieve 3 or 4 orders of magnitude in sensitivity improvement over the Sky Survey in this limited number of directions.

Table 1. Bi-modal Search Strategy for HRMS

Sky Survey	
DSS 13	1992-1994
DSS 24 and OVRO	1994-2001
DSS 34	2001-2003
1-10 GHz frequency coverage	
30 complete maps of the sky	
0.2 degress/sec scan rate	
Limiting sensitivity for CW	1,000-3,000 Jy
Targeted Search	
Arecibo	1992, 1995-2001
Parkes	1994-1995
NRAO 140 foot	1996-2001
Nancay	1996-2001
1-3 GHz frequency coverage	
1,000 nearby solar-type stars	
Limiting sensitivity for CW	0.3-50 Jy
for pulses	30 mJy - 3 Jy

Table 1 provides a summary of the observational sequences currently envisioned for the Sky Survey and Targeted Search. Note that OVRO will be used to complete the northern Sky Survey at frequencies near 1 GHz where DSS 24 does not function efficiently. Also note that the 140 foot antenna at Green Bank will be dedicated to HRMS observations once the GBT (Green Bank Telescope) is completed and that the use of Nancay as a large northern site is predicated upon a successful upgrade of the telescope optics.

As an example of what the limiting sensitivities in Table 1 can achieve, we note that the pulse detectors of the Targeted Search might just detect the 8 10^6 Watts of Effective Isotropic Radiated Power (EIRP) from broadcast TV leakage if it were coming from the distance of the nearest stars (4 light-years), but no further. In contrast, the Sky Survey could detect the analog of Earth's most powerful transmitter, the upgraded planetary radar on the Arecibo telescope, if it were located 100 light-years away, and the Targeted Search could detect it half way to the center of our Milky Way Galaxy (about 4,000 light-years). An advanced technology may well have a microwave downlink from a stellar power satellite producing 2 10^{17} Watts EIRP, or more. Such a signal has enough power to be detectable throughout much of the Galaxy!

While these sensitivities are impressive and far in excess of what has been possible before, we cannot guarantee that they are enough to yield a successful detection, or even that the comprehensive search for a broad class of signals is looking for the right thing. The only way to answer the question is to do the experiment!

WHERE WE'VE BEEN

On October 12, 1992, NASA celebrated the 500th anniversary of the discovery of the Americas by inaugurating the HRMS simultaneously at two sites. At Goldstone the 34 m antenna at DSS 13 began a Sky Survey of a patch of sky containing GL415.1A, a solar-type star 16 light-years distant, that was the initial target star for the Targeted Search at Arecibo Observatory. The road to these inaugural ceremonies had been long and often rocky, but all those enjoying the events that day hoped that the future would continue more smoothly and eventually lead to a successful detection; under whatever name, and within whichever institutional home!

Lessons learned at Arecibo

The observations at Arecibo concentrated on 24 solar-type stars visible from that site. These had the virtue that they passed nearly overhead and were uniformly distributed around the clock. For the inaugural observations, the Targeted Search interfaced with five of the line feeds (22, 21, 18, 12, 9 cm wavelengths) that provided about 300 MHz of frequency coverage at the site. In the future, we will make use of the wideband feedhorns and receivers that will be part of the Gregorian Upgrade Project for Arecibo.

The instrumentation used at Arecibo during October and November represented about 1/4 of what we envisioned to be our final complement of instrumentation, and was used to provide "lessons learned" prior to completion of the rest. Instantaneously, we observed 8 MHz of bandwidth with dual circular polarization. A Quadrature and Baseband Converter (QBBC) shifted the available IF signal from the line feeds on the telescope to baseband and digitized it with 8-bit precision after inserting a 90 degree phase shift. A fiber optic network delivered the digital streams of data to a Multichannel Spectrum Analyzer (MCSA) and then to a CW Detector (CWD) and Pulse Detector (PD) all of which were resident in a steel-lined trailer parked outside the equipment bay. This Mobile Research Facility (MRF) provided safe transportation, floor space and 80 dB of shielding to keep the digital noise from our digital hardware from radiating into the line feeds within our line of sight. The MRF proved its value for transportation (only 30 hours transpired between the landing of the military air cargo plane on the island and the successful operation of the equipment at the site) and for shielding (when the door facing the antenna was opened, we clearly detected ourselves), but it suffered from inadequate air circulation, faulty power connectors and a fragile air conditioner. Its virtues have been retained, and its faults have since been remedied.

Figure 1 displays the unique architecture of the MCSA, which has been implemented with a custom, VLSI, programmable digital signal processing chip for performing Fast Fourier Transforms (FFT's). For each sense

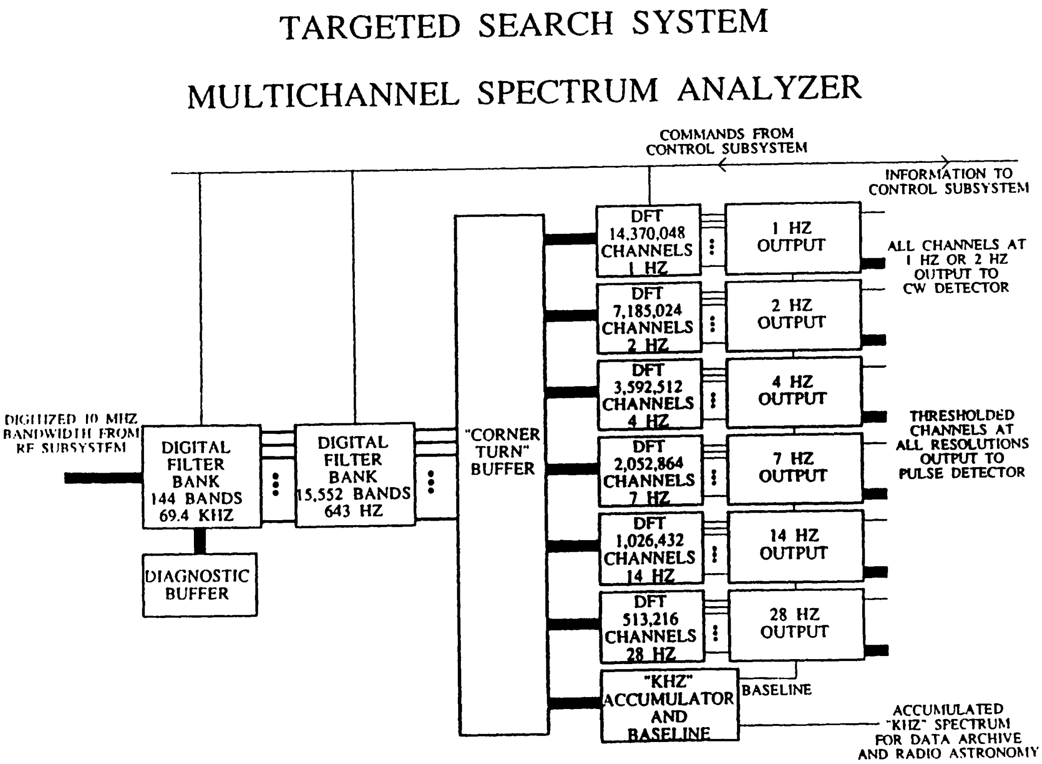

Figure 1. Architecture of the Multichannel Spectrum Analyzer (MCSA).

of circular polarization, two layers of cascaded digital filters divide the incoming signal into 144 bands of 74 kHz width and then into 15,532 subbands of 643 Hz width. Between adjacent subbands there is more than 80 dB of isolation so that strong sources of radio frequency interference (RFI) can be contained without spreading. Discrete FFT's of varying length then produce 6 simultaneous resolutions from 1 to 28 Hz to provide optimal matches to both CW and narrowband pulsed signals. As used at Arecibo, only resolutions of 1, 7 and 28 Hz were available. To reduce the mismatch possible between pulse arrival and sampling times, the data are overlapped by 50% in time, so that every 1.4 seconds two, nearly-independent spectra are produced at 1 Hz resolution, 14 spectra at 7 Hz *etc.* In all there are 14,370,048 channels of 1 Hz resolution and the equivalent data rate at each of the other resolutions. A dual polarization MCSA covering 10 MHz of input bandwidth has a sustained processing capacity of 50 GFLOPS!

The 1 Hz data from the MCSA is transferred to CWD (one for each polarization) and searched for drifting CW signals with an original DADD algorithm (Doubling Accumulator Drift Detector) implemented on a single complex, custom PC board. The rest of the detector is implemented with commercial cards and components whose main function is to read and write data to 10 GBytes of RAIDs (Redundant Arrays of Inexpensive Disks) storage per polarization. The CWD reports signal paths through the frequency-time plane along which there is excess power with respect to Gaussian noise. These reports are sent to a System Control Subsystem (SCS) computer that clusters multiple reports into a better representation of the signal that actually triggered the detector.

At the same time that the 1 Hz resolution data are being analyzed by the CWD, the PD looks at thresholded data from all resolutions and polarizations. Although one device is used to search out pulsed signals in all resolutions and both polarizations (up to 12 "flavors" of signal) simultaneously, it uses commercial processors and runs roughly 20 times slower than the CWD. This is because it searches a sparse data set in the frequency-time plane because of the thresholds applied by the MCSA. Nevertheless, the PD can find signals whose average power is less than their CW counterparts, as long as there are at least 3 pulses during the observation. The PD also reports all its candidate signals to the SCS for further clustering.

The SCS compares the best representations of signals reported by the PD and CWD against signals that have already been reported and stored in a dynamic database. If matches occur with signals observed from other directions on the sky, the new reports are labeled RFI, if no match occurs the signal becomes an interesting candidate for reobservation. All the signal processing (including the matching) takes place in near-real-time, that is in no more time than it took to acquire the data. One observational cycle after a frequency was observed, a list of remaining candidates for further action is available.

One of the biggest unknowns prior to the Arecibo deployment was the nature of the narrowband RFI in the vicinity of the observatory. Radio astronomers could tell us little about very narrowband signals at the sensitivity levels of interest to HRMS, and virtually nothing about the detailed temporal structure of the RFI. For this reason, each target and frequency combination was observed first on target, then off target and again on target. Each part of the cycle lasted 300 seconds at the beginning of the program and later, 92 seconds. In this manner we could explore the efficiency of an observational strategy based on database lookup and immediate reobservation of interesting candidate signals. The goal is to limit the time spent reobserving signals to about 25% of the total time.

Arecibo proved that this goal is unlikely to be achieved with a single telescope. At Arecibo, the RFI is strong, multitudinous, changes frequency rapidly in time and turns on and off with a timescale of minutes! This means that when the telescope is pointed off-target, there is a high probability that the RFI source will have tuned off. If it turns on again during the on-target phase it will trigger reobservations. Since the source may have turned off again by the start of the reobservations, proving that the same signal can be detected from different parts of the sky, and is thus interference, requires a lot of telescope time. During 200 hours of observing in October and November, 436 sequences of frequency/target observations were successfully completed, and of these, 15 presented the response expected of an ETI signal coming from the direction of the target star – all proved to be transient RFI!

The most useful lesson learned from Arecibo is that database lookup is inadequate for an efficient observing program. Something more is needed. That something more are the Follow Up Detection Devices (FUDDs) described elsewhere in this meeting. In the future, the Targeted Search will be conducted with two telescopes simultaneously observing the same target, and we will use the FUDDs to enable a "virtual interferometer."

Arecibo provided some additional lessons. We will need to avoid pointing the telescope too close to the moon. Observations centered at 1394 MHz clearly demonstrated the detection of over-the-horizon signals reflected from the moon. Also, we need not abandon a 10 MHz frequency band containing a strong persistent radar signal (from the San Juan airport, for example) The architecture of the MCSA allows for the recognition of such signals and the application of a "mask" to prevent the corrupted regions of the spectrum from being passed along to the hardware signal detectors. This is similar to the dynamic-masking employed by the Sky Survey (see below) and is one of the ways we have learned from our joint experience. As additional copies of the MCSA are produced, this feature will be enabled.

The database of all the signals detected at Arecibo is still being analyzed, as we look for better clustering rules and any patterns that may prove to be useful diagnostics. There may still be more lessons to be learned, and we always reserve the right to get smarter if we can afford it! One challenge will be to see if we can find some way to work around the unfiltered spread spectrum interference increasing daily from the GLONASS and GPS satellite navigational systems.

Lessons learned at Goldstone

The Sky Survey Prototype System (SSPS) has been installed at Goldstone since early in calendar year 1992. Much of the time prior to the inauguration of observations was spent learning how to interface its control computer to the Monitor and Control system that was being developed for the new 34 m beam waveguide antenna at DSS 13. Fortunately, as October 12th drew nearer, this became less of a moving target, and the Sky Survey team was able to embark on a program of X-band (8 GHz) observations of the sky as planned. Since DSS 13 is the R&D antenna for Goldstone, time must be shared with other groups, and the system is still developing to meet the needs of all its users. But useful Sky Survey observations have been steadily increasing in time, accounting for about 40 hours per week as of this writing.

The SSPS, shown schematically in Figure 2, is functionally equivalent to 1/16 of the final Sky Survey Operating System (SSOS). Unlike the Targeted Search equipment deployed to Arecibo, it is truly a prototype for testing concepts and will be replaced by a more efficient implementation over the next few years. The SSPS is manufactured with LSI wirewrap technology while the SSOS will be implemented with a custom VLSI FFT chip on

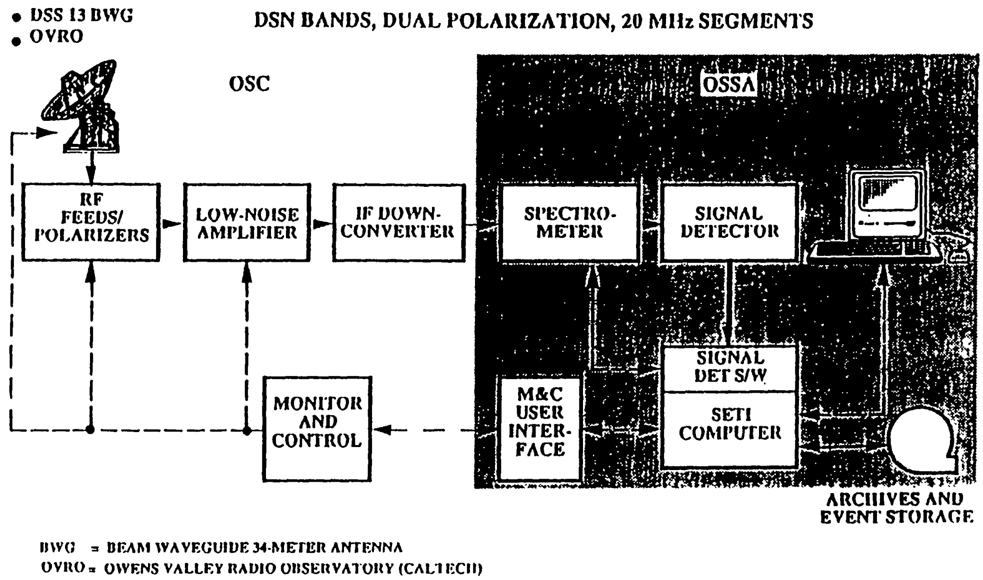

Figure 2. Block diagram of the Sky Survey Prototype System (SSPS).

fastwire boards. The SSPS permits analysis of 40 MHz of single circular polarization or 20 MHz of dual polarization input data, and produces 2 million spectral channels with center spacing of 19 Hz with an arbitrary windowing function applied in the time domain. The spectrometer portion of the SSOS will consist of four modules, each capable of processing 80 MHz of dual polarization input, producing an output resolution of 20 Hz by a combination of polyphase filtering and radix-2 FFT, to provide containment of strong RFI signals and a better approximation to an ideal matched filter.

The pattern recognition functions appropriate for the Sky Survey are currently implemented in the Baseline Convolution and Threshold (BECAT) subsystem of the SSPS. The BECAT works in conjunction with the precise control of the telescope around a "racetrack" scanning pattern (see Levin *et al.* this volume) to discriminate against RFI encountered during the search of each individual skyframe on the sky. The baseline (against which to threshold individual channels) estimation process is dynamic and invokes an order statistic. The baseline value for a sequence of 128 channels is determined by the 100th largest value therein, which is a more stable estimator than the mean power when strong RFI is present. As the antenna sweeps along a scan line, a 5-point convolutional filter, representing the beam pattern, is applied and events above a preset threshold are recorded as "singlets." Signals that are found at the same sky position on two adjacent scan lines are recorded as "doublets." Since the racetrack pattern imposes a time separation of about 10 minutes between coverage of the same sky point on adjacent scan lines, the rotation of the Earth and transverse velocity of satellites will cause RFI sources on the ground or in orbit to appear at different sky coordinates on adjacent scan lines, thus they will not be recorded as interesting "doublets." Beginning with the first scan line, masks are dynamically created to remove sources of RFI identified on the basis of "too broad" (the signal persists for multiple beamwidths along the scan line) and "too busy" (individual channels report events over threshold at far greater than the expected rate, spanning multiple scan lines) software tests on the recorded singlets and doublets. Immediately following the completion of each skyframe observation, additional algorithms are employed to find and delete intermittent bursts of RFI and RFI signals that drift rapidly in frequency, and then the strongest 10 singlets and doublets are reobserved in a targeted mode.

A conical scan pattern is executed around the positions of these potential candidate signals, and any that are re-acquired are subjected to further observational tests. To date the observations at X-band have enjoyed an interference-free environment that has permitted the attainment of the expected noise-only false alarm probability of 10^{-11}, with only two candidate signals persisting through the initial lookback and requiring additional observing to verify that they were RFI. To first order, the BECAT architecture is proving robust against RFI. For the SSOS, many of the algorithms will be captured in special purpose signal detection hardware to improve the throughput speed. The experience gained at Goldstone is being factored into the design and implementation of all aspects of the SSOS.

One of the most significant achievements of the Sky Survey observations at Goldstone is the fact that they no longer require a presence at Goldstone to conduct them. Since the monitor and control of the 34 m at DSS 13 has begun to stabilize, it has been possible to run routine skyframe observations and reobserve the interesting candidates remotely from JPL. By now more than 50 skyframes have been mapped at X-band, covering 40 MHz of bandwidth in two circular polarizations.

To verify the proper functioning of the SSPS, spacecraft with X-band transmitters are routinely observed and detected. The SSPS was briefly used in an attempt to reacquire signals from the Mars Observer Mission spacecraft, with unfortunately no success.

In order to prepare for the secondary objective of providing serendipitous radio astronomical data during HRMS observations and to explore a more interference-ridden spectral regime, the SSPS made use of a 26 m antenna co-located at DSS 13. An old L-band feed and receiver system were installed on the 26 m to enable observations with a system temperature of 80 to 100K. With this system, three skyframes in the galactic plane extending from 350 to 20, 20 to 50, and 60 to 90 degrees of galactic longitude and ± 2.5 degrees of galactic latitude were repeatedly mapped. For these observations, the fields were fully sampled with a spacing between scan lines of 1/2 half-power beamwidth. In all, about 150 of these L-band skyframes were observed and algorithms for registration and gain correction are being developed to permit the co-adding of the successive maps.

Observations of OH masers led to the discovery of an offset in the L-band LO system, and examination of the order statistic output permitted the recognition of a strong pulsar from the non-symmetric signature imposed on the higher order moments of the noise distribution by interstellar scintillation. Even at the isolated Goldstone site, many of these L-band observations were dominated by RFI, some of it was occasionally severe enough to obscure 50% of the observing window. New algorithms for dealing with this less benign environment are being developed for the future. These useful exercises terminated in the spring when the 26 m antenna was decommissioned and dismantled.

To date the Goldstone observations have indicated that routine skyframes can successfully run on the new 34 m beam waveguide antennas in an unattended mode. At X-band, the observations are noise dominated, but at L-band RFI is a difficult problem. While it will not be routine for some time to come, useful radio astronomy data can be extracted from the HRMS skyframe observations.

WHERE WE'RE GOING

For the past few years a common design for RF feeds and receivers for use by both the Targeted Search and Sky Survey has been under development at JPL and Ames. The first of these is currently being fabricated at JPL and the CSIRO in Australia in anticipation of major observational campaigns in 1994 and 1995. This will be the first time that HRMS will have access to continuous frequency coverage from 1 to 10 GHz, with low-noise, wideband systems capable of providing system temperatures less than 25 K. Two feed/receiver packages will cover 1 to 3 GHz and two more will span the range of 3 to 10 GHz. They all utilize an up-down conversion scheme to shift from RF frequencies to a 600 MHz IF where the unique Targeted Search and Sky Survey signal processing systems are interfaced. Cryogenically cooled orthomode transducers produce two orthogonal linear polarizations that are converted to circular polarization after the low noise amplifier stage. Both prime focus and Cassegrain feeds have been designed with the optics matched to the DSN and radio astronomy telescopes to be used in future observations.

In the fall of 1994, the Targeted Search will take advantage of a window of opportunity and begin a sixteen week observing program in Australia. All target stars south of −35 degrees declination will be observed from the 64 m Parkes Observatory and simultaneously from the ATNF 22 m Mopra antenna at Connabarabran. FUDDs at both Parkes and Mopra will attempt to verify and interferometrically confirm the existence of candidate signals without the need to interrupt the observations to perform off-on-source lookbacks. This will be the first observational use of the FUDDs and performing southern hemisphere observations in the austral summer will be challenging for the observational scheduler. Preliminary calculations indicate that a solar-avoidance angle of 50 to 60 degrees may be required to prevent solar wind scintillation from broadening intrinsically coherent signal components beyond the 0.01 Hz that permits minimum detection times with the FUDDs. The observational sequence will be interrupted to permit periodic pulsar timing measurements at Parkes and it will be followed by a two week "cooperative science" period. During this latter period, approved observing proposals for additional SETI observations or traditional radio astronomy studies with the Targeted Search instrumentation will be conducted in collaboration with the proposing scientists.

Upon its return from Australia, the Targeted Search will further augment its observational bandwidth while awaiting the completion of the Arecibo Gregorian Upgrade Project, the completion of the GBT and the upgrades at Nancay. From 1995 through 2001 the Targeted Search will use the NRAO 140 foot antenna as a dedicated site searching for long-period pulses, and will co-observe with the 140 foot during campaigns to Arecibo and Nancay until all targets and frequencies are covered.

As the Targeted Search prepares to ship equipment to Australia in the summer of 1994, the Sky Survey will commence the low frequency portion of its search at OVRO. Using the wideband RF systems for the HRMS and a new monitor and control system that is now being installed at OVRO, scientists at JPL will routinely map the sky near 1 GHz for 5 months, completing the survey with an additional 5 months of observing during the summer of 1995. The 40 m telescope will be available full time during these summer campaigns, and plans call for devoting about 50% of the time to specific astronomical observations by members of the HRMS IWG. During this time the SSOS will be under construction, the first 80 MHz module being delivered in 1996. This will permit the Sky Survey to proceed with the routine survey at DSS 24, using the wideband HRMS RF system for an average of 16 hours per day. As additional 80 MHz modules of the SSOS are added, the rate at which the sky is observed increases dramatically. In 2001, having completed the northern sky survey, the SSOS will be moved to the Tidbinbilla DSN station and spend 3 years completing the survey of the southern sky.

Projecting observing schedules a decade into the future has become routine for the community involved with spacecraft observations, but it is still fairly rare for ground based observers. Whether the observations will in fact take place exactly as described remains to be seen. The requested budget, telescope resources, spares for electronic equipment, and plans for data management and archival are all consistent with the program described. Of course the detection of a signal could disrupt the plans at any moment! A Signal Detection Protocol has been drafted to deal rationally with that happy eventuality. If the HRMS observational program is successfully completed without the detection of a signal, what then? Plans and studies are now commencing to determine the most reasonable next step. Those of us involved in HRMS hope for signal detection, but fully realize that this may be only a first step and many more may be needed.

Even if no signals are detected during HRMS, there will be predictable by-products worth the effort. As a result of large scale observational programs, the local stellar neighborhood will be much better characterized by IWG members and their collaborators. Stellar ages and companions will be added to the inventory of what is already known about the nearest few thousand stars. The wideband, low-noise, spur-free RF and IF systems designed for HRMS may find application in more traditional astronomy. Continuum maps of the sky from 1 to 10 GHz will be produced with sensitivity comparable to those already made over restricted frequency ranges. The possibility for detecting distant galaxies in the "zone of avoidance," masers at unpredicted frequencies, new pulsars, high velocity HI clouds, and even the spectral line signature of the axion are all being pursued. Lastly there is always the potential for the discovery of new emission processes in nature. We are employing a unique set of observational filters and will be spending many hours observing the universe. There is ample historical precedent to suggest that we may detect the unexpected.

Where We're Going (updated)

Shortly after the Santa Cruz meeting, the U.S. Congress acted on an amendment by Senator Bryan (Democrat, Nevada) and terminated funding for the HRMS in the name of deficit reduction. The SETI Institute in Mountain View, California immediately began a campaign to raise private funds to continue the search effort.

Because the Sky Survey portion of HRMS relied so heavily on NASA's DSN antennas, it has not yet been possible to find a way to continue the sky survey effort. Work on the SSOS at JPL was terminated, and the SSPS remains at DSS 13 as an augmentation to support special activities related to spacecraft communications and radio astronomy research. In the case of the Targeted Search, much of the required observing time had already been awarded or negotiated and was still available. The SETI Institute arranged with NASA for a long-term loan of the equipment that had been deployed to Arecibo. As soon as funds became available it began doubling the bandwidth of the equipment and planning for a five month Australian observing campaign as the first stage of what is now known as Project Phoenix.

The observing goals of Project Phoenix mirror those of the HRMS Targeted Search. In addition, Phoenix has proposed to improve the search capability of its equipment by a factor of ten during the coming decade, and has begun long range plans for an array of new, dedicated SETI antennas as the next major improvement in search capability. As this volume is going to press, sufficient private funds have been raised to ensure the Australian observations, and fund raising is now concentrating on providing sustained annual budgets sufficient to permit a long-term search effort.

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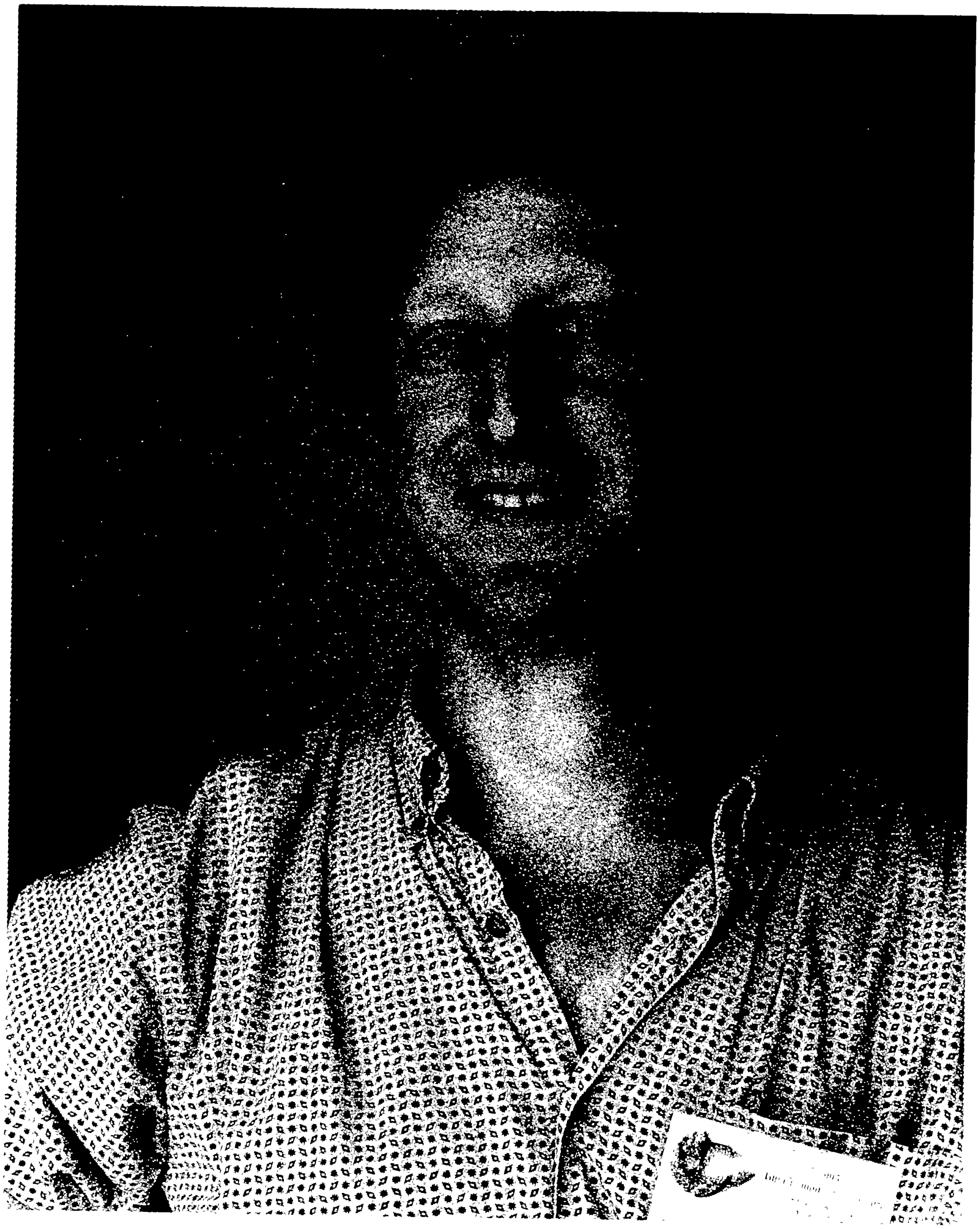

Steve Levin considers all the solid angles.